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ACCIDENTAL RADIATION EXCURSION AT THE OAK RIDGE Y-12 PLANT

PART II - HEALTH PHYSICS ASPECTS OF THE ACCIDENT

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The information presented here is one part of a series of four articles which collectively describe the accidental nuclear excursion which occurred June 16, 1958, in the Union Carbide Nuclear Company, Y-12 Plant at Oak Ridge, Tennessee. This discussion is submitted for publication in Health Physics, the official journal of the Health Physics Society in the interest of further dissemination of information concerning this unique event.

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INTRODUCTION

On June 16, 1958, the first known accidental and unscheduled nuclear chain reaction to occur in an industrial process facility took place in the Union Carbide Nuclear Company Y-12 facility for the recovery of enriched uranium from fuel fabrication scrap and other salvage.

In an incident of this type, the hazard of first concern is not a high order nuclear explosion, but instead the lethal radiation which accompanies the incident. Of secondary importance, but of real concern to those who must combat the hazard, are the radiation after-effects. This discussion purposes to generally describe the conditions encountered during the course of the Y-12 incident and the Health Physics measures taken to evaluate and regain control of the area.

BACKGROUND

To best understand the Y-12 situation, distinction should be made between chemical processing facilities for the preparation of "cold" enriched uranium, which has relatively little radioactivity, and those designed to recover uranium from "hot" irradiated reactor fuel by separation from the highly radioactive fission products. In the latter case, protection must be routinely provided against the ever-present radiation hazard. Accordingly, such operations are shielded and controlled remotely. These requirements provide, in addition, a certain measure of protection against nuclear accident consequences. In the case of "cold" material, such as that handled in the Y-12 facility, the radiation problem is not acute; thus, the materials and equipment are accessible as a matter of routine. Personnel, in large numbers, frequent the area with relatively free access.

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* The information presented here was taken generously from material gathered and prepared through the unselfish efforts of many people, who contributed to the preparation of report Y-1234, "Accidental Radiation Exposure at the Y-12 Plant".

For many years, a successful program of nuclear safety has been carried out in Y-12. This program, while obligated to the principle of preventing even a single nuclear excursion was, and remains, contingent upon human capabilities. Since safety is never absolute, the program assumed that a nuclear excursion could occur. Accordingly, plans were made to provide capabilities to detect and combat such an incident. This plan may be described as follows.

1. Detection of Incident and Sounding of Alarm

   Although physical damage could occur, one cannot depend upon fuming, boiling, explosion, or a blue glow or haze as the only means for detection of a nuclear reaction. Further, prompt action must be taken with a minimum of time lost to make decisions. Accordingly, gamma sensative radiation detectors have been installed in all areas wherein potential criticality hazards exist. The monitor system in Building 9212, the location of the incident, is composed of six permanently-mounted instruments, a siren system audible throughout the building, and an annunciator system which indicates the location of an activated monitor. Any one of the six monitors automatically actuates the alarm sirens when the dose rate at the instrument exceeds 3 mr/hr. The utility of such a system is the fact that the alarm so given indicates the presence of a radiation hazard and implements emergency action with a minimum of lost motion. It cannot predict a nuclear excursion, and thus is after-the-fact, but it may, through the establishment of a prompt alert, minimize subsequent personnel exposures.

2. Evacuation of Area

   In case of a monitor alarm, quick orderly evacuation by the most direct route away from the processing area is considered to be the best path for the majority of people to follow. In some cases, it may be possible to provide sufficiently flexible evacuation signals so that evacuation routes are always away from the scene of a nuclear reaction. In the subject case, however, the former procedure is used due to the complexity of the plant layout, leaving to chance the possibility that any given evacuation path could pass closer to the accident location. By prompt evacuation of the affected area to preselected assembly stations, control over the group is established in case of need for further action.

3. Initial Survey of Area and Personnel

   Beta-gamma survey meters are maintained in pairs at three locations at the perimeter of the area of concern. Local emergency squads, trained in survey procedures and maintained routinely in all hazardous areas, assemble immediately upon monitor alarm. They collect the instruments provided and survey the assembly areas, moving personnel as necessary to keep them in a radiation zone of less than 5 mr/hr. These teams also check for gross personal contamination (> 1 r/hr) using the available portable survey instruments. Persons found to be contaminated should have their contaminated clothing removed immediately and should be sent to shower without delay.

4. Screening of Personnel for Signficant Exposures

Upon verification of the occurrence of a nuclear incident, evacuation of personnel proceeds to selected secondary locations where survey teams monitor security badges for indium foil activation and check personal contamination further. As a matter of routine procedure, indium foils have been placed in all security badges for the purpose of quick identification of those persons who may have been exposed to neutron irradiation arising from a nuclear reaction. The intent of this procedure is to identify those cases of significant exposure, particularly any which may be serious or critical. Such cases may then be directed to the Medical Dispensary for treatment and/or observation. Facilities for decontamination are available in these locations if needed.

5. Follow-Up Area Survey and Rehabilitation

As soon as feasible after activation of the plant emergency plan, trained survey teams, which are made available locally and through pre-established mutual assistance plans with others, are dispatched to the radioactive area. These teams monitor toward the reaction location and establish boundary lines at 12.5 mr/hr and 125 mr/hr. Simultaneously, efforts are made to determine the extent of environmental contamination by direct measurements and by air-sampling. Areas found to be unaffected, or within permissible limits, are released for rehabilitation as the surveys progress. Continuing control is exercised over the area until the radiation intensities permit access to the immediate area and suitable disposition is made of the source.

CONDITIONS ENCOUNTERED AND MEASURES TAKEN FOLLOWING THE INCIDENT

Preliminary Surveys

At approximately 2:05 p.m., June 16, 1958, sirens of the radiation monitoring system sounded the alarm in Building 9212, implementing the building evacuation plan. Immediately, process supervisors, equipped with emergency radiation survey meters detected, and confirmed by multiple readings, radiation intensities of more than 100 mr/hr at the building control center, a distance shown later to be about 350 feet from the location of the accident. The Plant Emergency Director, who was present at the time of the alarm, acted to put the plant emergency plan into effect, thus evacuation of personnel from primary assembly points to secondary control centers proceeded with little further delay. See Figures 1 and 2 for locations.

The local emergency squad surveyed the west and north ends of the building, observing readings of 50 to 100 mr/hr. During this same period, radiation was detected by laboratory supervisors at the north end of the Analytical laboratory, approximately 400 feet east of the accident scene, at first fluctuating in intensity up to ≈ 1000 mr/hr and shortly thereafter up to 500 mr/hr. It is perhaps significant to observe that the building is oriented in such a manner that the corridors and operating areas extend in an east-west direction. It is reasonable to assume that less attenuation occurs to the east and west due to lack of walls and absence of bulky operating equipment. The area is cross-walled and heavily equipped to the north and south.

The radiation detected up to this point made it clear that the incident had occurred within Building 9212 with the precise location yet to be determined. Continuing surveys along the outside of the perimeter fence recorded readings of up to 50 mr/hr for a period of about twenty minutes, after which time the levels dropped to 5 to 10 mr/hr.

Survey of Environs and Detection of Released Activity

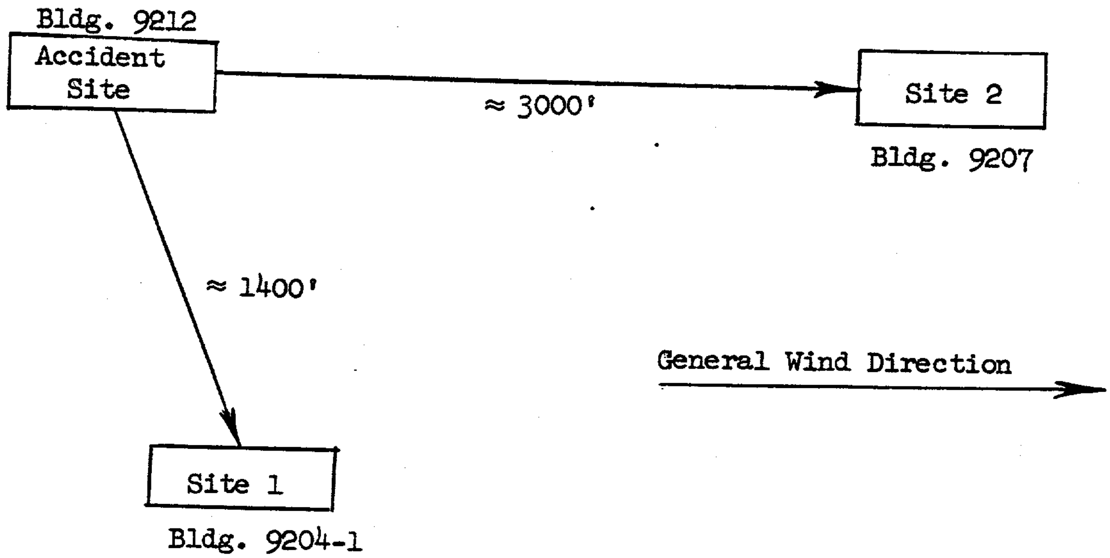
Radiation surveys were made of the plant area to obtain an over-all evaluation of conditions. Within an hour after the incident, it was determined that there was no direct radiation or significant contamination outside the perimeter fencing, which forms the security area in which Building 9212 is located. This area, approximately 800' x 1000', was subsequently marked off as the initial delimitation area.

Efforts were made to survey the environs and detect the release, or subsequent fall-out, of fission product activity. High-volume air samplers were set up outdoors at five locations ranging from ≈ 700' to ≈ 3000' down wind from the accident. Sampling was, unfortunately, not begun until about 50 minutes after the incident and 20 minutes after the ventilation supply and exhaust fans for the area involved had been cut off. The samples, obtained by drawing air through Whatman No. 41 filters, were counted for alpha and beta-gamma activity.

These samples indicated a maximum concentration of 2.5×10^{-11} $\mu c/cm^3$ beta-gamma activity as of the time of collection. This is well below the 10^{-9} $\mu c/cm^3$ permissible level of air-borne activity suggested by the National Committee on Radiation Protection.[1] As would be expected, no significant air-borne alpha contamination was detected.

[1] Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water, National Bureau of Standards, Handbook 52. (1953)

Some indication of air-borne contamination released to the atmosphere may be obtained from inspection of two continuously recording beta-gamma air monitors which were located as shown in the sketch below. These monitors are Geiger-Muller tube instruments measuring and recording the beta-gamma emission from particulates collected from an air stream on a fixed filter paper. The tubes are surrounded by the filter and are shielded by 1-1/2 inches of lead.



Both instruments detected the initial direct gamma radiation from the actual excursion and both showed subsequent increases in the level of atmospheric beta-gamma contamination. The following observations are made from inspection of the charts from these instruments. See Figures 3 and 4.

1. The level of initial direct radiation recorded at Site 1 was higher than that observed at Site 2 because of the distances involved.

2. The air-borne contamination, however, reached Site 2 much sooner (10 minutes vs ≈ 45 minutes) and in higher concentrations (considerably more than a factor of three), since it was directly downwind.

3. Because of the short half-lives of the fission products, < 2 hours, and the relatively short length of exposure of any persons to the contaminated atmosphere, the concentrations detected constituted no acute hazard.

4. Considering the favorable conditions of wind velocity and direction existing at the time and the levels of concentration detected, it can be stated, with a high degree of confidence, that no significant concentrations of these activities reached any nearby populated areas.

Surveys were made of the parking lots along the north side of the plant site, these lots being located generally east and west of the accident area. Spot checks were made on the ground, paved areas and automobiles. No evidence of beta-gamma contamination was detected and the automobiles were consequently released.

Survey of Accident Site and Rehabilitation of Area

Within an hour and a half after the excursion, teams of health physicists began approximating the site of the incident by a series of perimeter radiation surveys. The radiation and contamination levels encountered were quite low, ranging from 0.2 mr/hr at the boundary of the primary delimitation area to 10 mr/hr at distances of approximately 200 feet from the drum. Although some spillage of materials had occurred in a few areas due to unattended operating equipment, no serious contamination levels were encountered. Boundary limits were adjusted to permit employees to re-enter all areas except those within the secondary delimitation boundary ($\approx$ 350' x 400') shown in Figure 1.

Some three hours after the incident, an emergency team undertook a cursory survey of the salvage area itself in which the reaction had occurred. The radiation dosage rate at the southwest door of this area, a distance of approximately 100 feet from the drum, was 60 mr/hr. When the men emerged, after being in this location for about ten minutes, the canisters of their gas masks read from 10 to 15 mr/hr, indicating that significant concentrations of air-borne contamination still existed in the area. Radiation measurements, direct and by air-sampling, were continued in the zone proximate to the accident area. Within a few hours, it was possible to relax the restriction boundaries to that area indicated as the tertiary delimitation area in Figure 1.

Control stations, manned by health physicists and stocked with the necessary items of protective equipment, were set up in the hallways to prevent unauthorized entry into this restricted area. Authorized persons were permitted to enter the controlled zone only in teams of two or more. Each team carried at least two radiation survey instruments. Required protective equipment included coveralls, shoe covers, stocking caps, rubber gloves, and either an MSA "All Service" mask with an ultra filter or a U.S. Army assault mask M-9 with an M-11 canister. Each person wore direct-reading pocket dosimeters and a film badge and each was surveyed for personal contamination upon return from the controlled zone.

In order to prevent the spread of air-borne contamination from the controlled zone to other parts of the building, a small fan, which exhausted through a CWS filter, was turned on, thus maintaining the area under negative pressure.

A cadmium scroll was inserted into the drum by manipulation of a ten-foot pipe, which was adapted for the purpose. This action provided positive assurance of nuclear safety and permitted a more detailed survey of the area.

Such a survey was undertaken with the following results being recorded about nine hours after the excursion:

Approximate Position	Reading* (r/hr)
20 ft east of drum	1.1
12 ft east of drum	4.7
8 ft east of drum	9.8
12 ft west of drum	3.6
8 ft west of drum	8.0
12 ft north of drum	3.6
8 ft north of drum	9.8
2 ft north of drum	81.0

"Wipes" or "smears" of the floor near the drum indicated that surface contamination had been confined to the immediate vicinity of the drum. The highest activity detected on these smears was 250 mrad/hr., direct reading from the smear itself, and 16,000 $d/m/100cm^2$ alpha contamination. Normal alpha contamination usually ranges from 500 - 1000 $d/m/100cm^2$. The fact that the active solution was confined to the drum itself was fortunate since widespread contamination would undoubtedly have seriously hampered reoccupation and rehabilitation of the area.

The drum of poisoned solution was allowed to sit intact until the morning of the second day following the accident. During this time, additional activity measurements of the drum were made. Some indication of the decay of radioactivity is shown below:

Date	Time	Reading (r/hr)	Position
June 16	10:32 p.m.	81	at 24 in. - middle of drum
June 17	10:30 a.m.	100	at 3 in. - middle of drum
June 18	10:00 a.m.	48	at 3 in. - middle of drum

After the immediate nuclear hazard had been disposed of by the addition of cadmium, the problem of removing the highly radioactive solution from the operating area was approached. It was decided to install "safe" tankage in an available radiographic cell some 200 feet east of the drum location and to vacuum transfer the solution via stainless steel tubing into this system, where it would be allowed to decay prior to reprocessing.

*All readings were taken with an ionization chamber instrument (cutie pie) approximately three feet above the floor with the exception of the last reading. The reading two feet from the drum was made at a height above the floor of approximately one-half the height of the drum.

Monitoring services were provided during the preparation for transfer of the solution to the shielded safe storage vessel. Dosimeters, worn by persons installing the vacuum transfer line indicated that no persons received any appreciable gamma dose (i.e., less than 300 mr) while making these preparations.

On June 18, vacuum transfer of the solution from the drum to the safe containers was begun. Radiation intensities, a few inches from the line, varied from 50 mr/hr to 80 mr/hr during transfer of the solution. During flushing of the drum and line with water, the radiation intensity dropped from 38 mr/hr during the first 5-gallon flushing to 5 mr/hr during the second 5 gallon flushing. Following this action, the following conditions were noted:

Empty line at exterior surface:	1 mr/hr
Top of empty drum; exterior surface:	5 r/hr
Near bottom of drum, exterior surface: (Due to sludge in drum)	30 r/hr

After the active solution had been successfully transferred to shielded safe storage and the drum removed from the area, the boundaries of the control area were moved in to encompass only the operating wing itself ($\approx$ 50' x 400'). Contamination surveys and air samples were continued. By early afternoon of June 18th, approximately two days post-accident, it was determined that the exhaust ventilation fans could be turned on without significantly contaminating the surrounding areas. Subsequent air samples were well within permissible levels; personnel were then allowed to enter the accident area without respiratory protection.

Decontamination of the area proceeded as the area was released by the investigating authorities. Routine monitoring and smear surveys were made to help direct and evaluate the decontamination efforts. On June 23, one week after the accident, all facilities were returned to normal operations.

SURVEY OF PERSONNEL FOR RADIATION EXPOSURES

Since 1955, strips of indium foil (approximately 1 gram each) have been included in the security badges of all employees at Y-12. The purpose of these foils is to provide a quick positive means for segregating employees who receive a significant radiation dose in the course of a nuclear reaction. This determination is accomplished by the measurement of beta and gamma radiations from the radioactive In^{116} isotope which is produced by neutron irradiation of the stable In^{115} isotope in the foil.

Following assembly of personnel at the two secondary control centers, checking for indications of neutron activation of the indium foil in their badges and for evidence of personal contamination was undertaken. Those persons whose badges gave evidence of possible high neutron doses were directed to the dispensary for further tests and medical attention. As a result of this process, twelve persons out of approximately 1200 surveyed were sent to the dispensary within two hours after the incident. The maximum reading observed during these checks was 60 mr/hr. In the five most significant cases, badge readings exceeded 20 mr/hr two hours after exposure.

In order to insure that exposure cases had not been overlooked, badges were collected at the gates when personnel were released and each badge was subsequently processed for dose determination. In the course of these and the prior badge checks, about 4500 activity readings were made.

Those persons who were sent to the dispensary were checked for personal contamination, interviewed briefly, and their badges rechecked. Individuals showing evidence of beta and gamma body contamination were scrubbed at the dispensary decontamination facility with soap and water and mild acids.

No attempt will be made to further describe the details of the evaluation of personnel exposures since this information will be treated more fully in other parts of this series. Suffice it to say that the use of indium foil in the security badges made possible the early identification of employees who had been in the immediate vicinity of the reaction and facilitated their segregation from unexposed employees. A possible unmanageable flood of employees to the dispensary was thereby forestalled.

SUMMARY

The Y-12 critical incident was unique, sudden and clean. Of particular note is the fact that the radioactive solution which comprised the reactor fuel was well contained within the reactor vessel, thus no extensive decontamination of persons or facilities was required. Further, the distribution of fission products to the environs was limited so that no serious complications were encountered in the plant area. The seriousness of the incident was lessened by the fact that no physical violence was involved in the reaction. Rehabilitation of the area and resumption of activities was possible in a minimum amount of time. Identification and segregation of all seriously-exposed personnel was accomplished with reasonable dispatch. In this respect, the use of indium foil as an identification medium was proven to be successful.

It should not be inferred that the conditions encountered in this incident are characteristic of the consequences to be expected as a result of future nuclear accidents. Rather, in view of a number of unique, fortunate circumstances which reduced the Y-12 problem significantly, it is reasonable to assume that consequences in other cases could be much more severe.

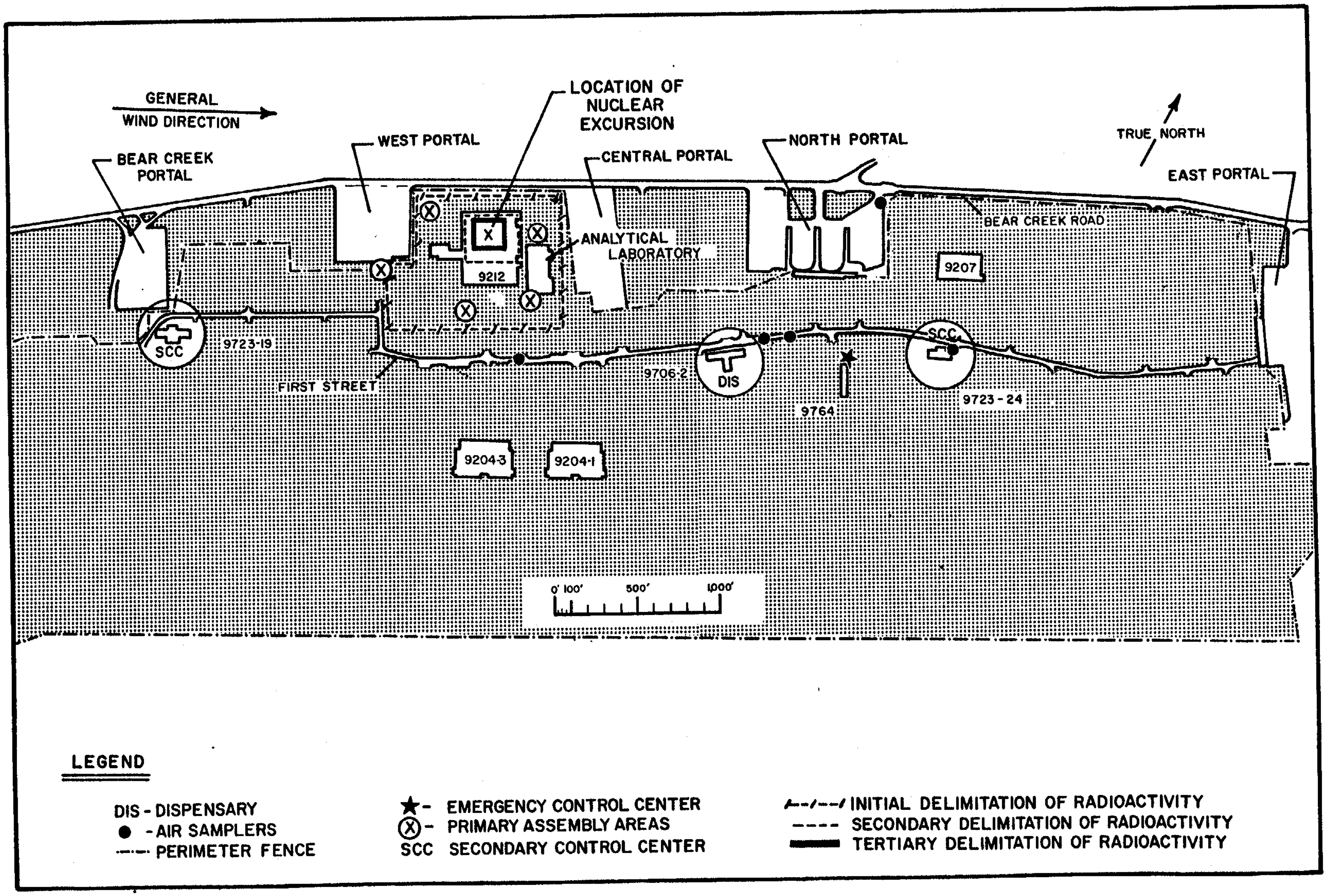
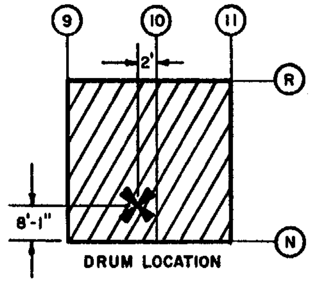


Figure 1

LOCATION OF Y-12 PLANT BUILDINGS PERTINENT TO INCIDENT



REFERENCE ILLUSTRATION: FIGURE 2

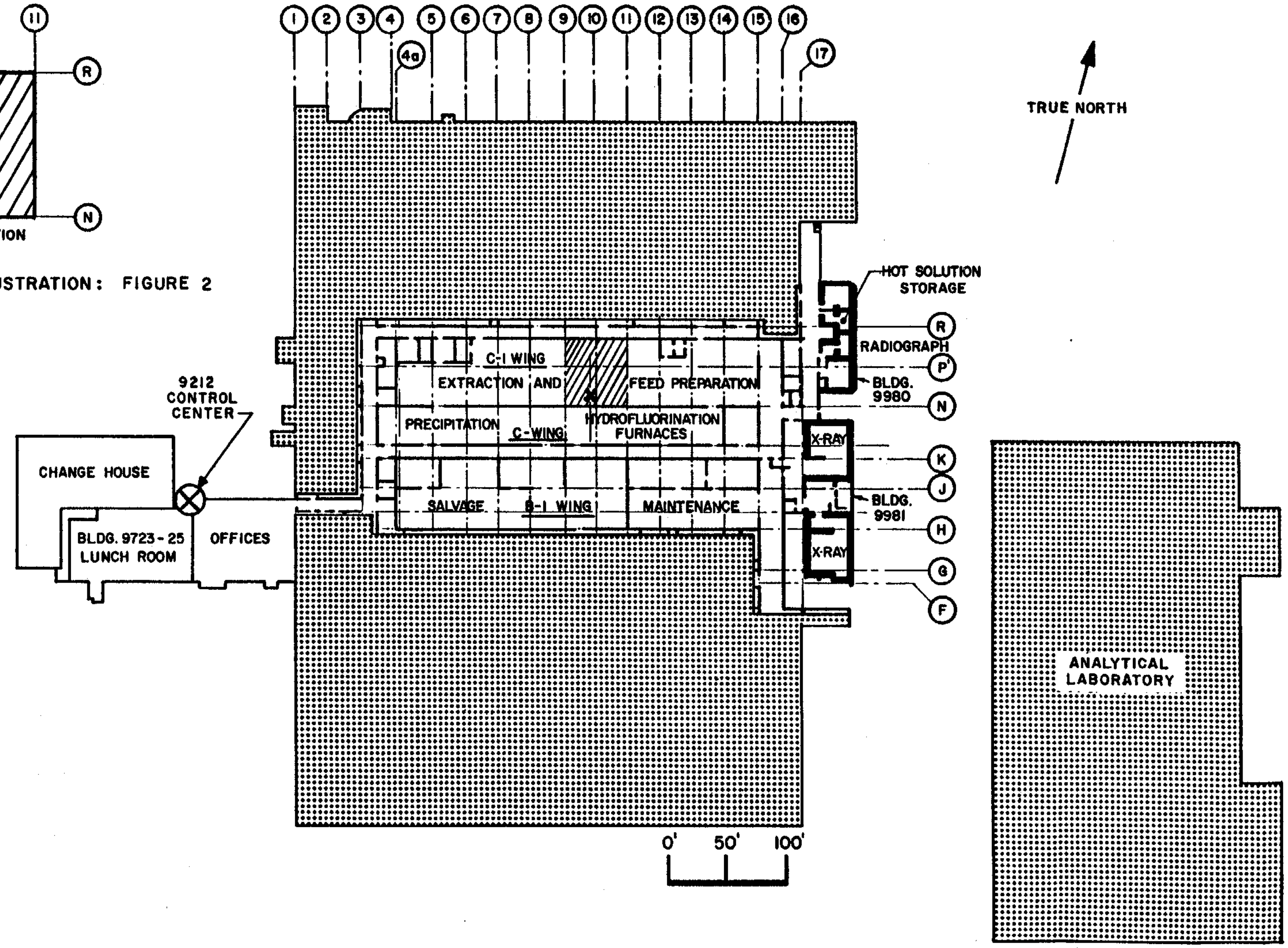


Figure 2
LOCATION OF NUCLEAR EXCURSION
Building 9212

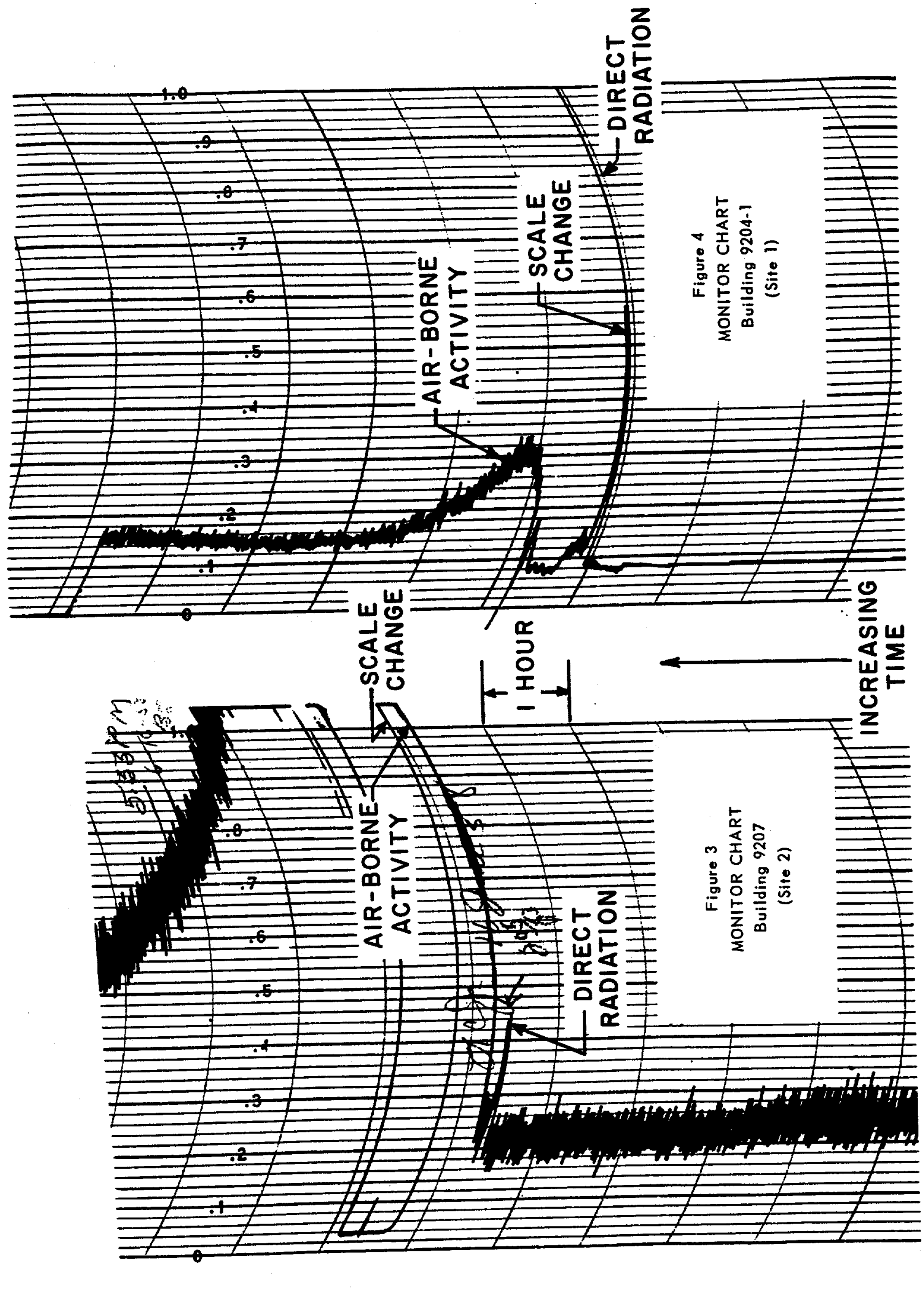


Figure 4
MONITOR CHART
Building 9204-1
(Site 1)

Figure 3
MONITOR CHART
Building 9207
(Site 2)